Natural Resources Canada

Energy
Technology
Futures

Results from the Renewable Energy Focus Group

Draft #1

Held on February 18th, 1999
National Research Council
Ottawa, Ontario
Compiled By Paul Khanna, 05/03/99

Canada

DISCLAIMER

This document represents the first draft using information from the focus group as well as the Ontario Center for Environmental Technology Advancement (OCETA) report ***Alternate and Renewable Energy Technologies for the Future: 2030 and Beyond***. This document and others can be found on the ETF website at **http://www.nrcan.gc.ca/es/etf**. To download these documents in Microsoft Word or Corel WordPerfect format, visit **http://www.nrcan.gc.ca/es/etf/vipsonly.htm**. This document may contain errors and inaccuracies that will be amended in the final draft. Please direct corrections and comments to Paul Khanna at (613) 943-9216 or email pkhanna@nrcan.gc.ca.

INTRODUCTION

The Energy Technology Futures group organized a focus group on alternative and renewable energy on February 18th, 1999 to reinforce and expand on our existing knowledge and understanding. It also served to bring together a diverse group of people in the field of renewable energy covering many aspects of this broad industry. The conference was held at the National Research Council building in Ottawa, Ontario.

BACKGROUND

MISSION STATEMENT

The all day session began with an outline of the Energy Technology Futures project and a mission statement for the day. The mandate to the group was to:

- Brainstorm possible alternative and renewable energy systems for Canada in the period 2030 to 2050
- Identify key technologies that Canadians could be using in that period
- Identify R&D priorities for the area, and critical paths, technology gaps, and barriers to implementation

The focus group developed perspectives on the future of renewable energy by three methods:

- A chronological step out to the year 2050 identifying technological milestones and energy technology mixes
- A visioning set in the 2030 to 2050 era outlining how we live, work, and travel
- A geographical perspective developing likelihood of technologies being used in certain areas of Canada

The last item on the agenda was a roundtable discussion concerning the ETF process and the role of the federal government in the field of renewable technology

CONTRIBUTORS

The focus group had eight outside attendees. They included contributors from industry, government, and academia. The list of attendees is as follows:

Claude Barraud, ETB, NRCan
Guy Belanger, IREQ
Andre Filion, CEDRL, NRCan
Stephen Harrison, Queen's University
Morel Oprisan, ETB, NRCan
Douglas Sparks, Hydro Québec
Jack Templin, Aero-electricity Consultant
Tony Tung, ETB, NRCan

Also present were three members from the Energy Technology Futures office.
Kevin Cliffe, Director of Energy Technology Futures
Glen Milne, Facilitator of the focus group.
Carole Champion, Science Advisor, Energy Technology Futures
Paul Khanna, Technology Advisor, Energy Technology Futures and group organizer

NOTES ON THE REPORT

The results from the focus group have been arranged into a readable report outlining the energy generation, storage, and transport possibilities for renewable energy, the possible futures of renewable energy, what technologies will be needed, and how Canada can meet future challenges. Additional details have been added for clarity and drawing conclusions. A glossary of terms is located at the end of this report for reference purposes.

ENERGY GENERATION

Renewable energy has the ability to extract energy from many different sources. Energy can be generated into many forms including electricity, heat, cold, liquid fuels, and hydrogen. Renewable energy sources have the capacity to meet all these needs although not always directly. The area of sources includes solar, wind, biomass, hydropower, earth based thermal, tidal, current, and wave energies. These sources and technology options identified by the focus group are outlined in the following section.

SOLAR

Solar energy can be categorized into photovoltaic generation for electricity and solar thermal for heat. To increase the amount of incident radiation against the receivers, the sun is usually tracked. With current technology, the sun must be tracked mechanically as it moves across the sky. Non tracking solar generator/reflector films were identified as a technology that would increase the efficiency and reduce the chances of mechanical failure for all types of solar arrays.

Photovoltaics

Photovoltaic cells convert sunlight directly into electricity by the interaction of photons and electrons between two types of semiconductor material. A semiconductor is different from a conductor because an energy barrier called the band gap. The band gap energy must be overcome before a current can flow. In conductors the band gap is effectively zero, in semiconductors, it is up to 5 electron volts (eV, $5eV = 8.0\times10^{-19}$ J). To create a photovoltaic cell, a material such as silicon is doped with atoms from an element with one more or less electrons than its substrate. A thin layer of each material is joined to form a junction. Photons striking the cell cause this mismatched electron to be dislodged and move across the junction, an outside circuit moved thus creating a current.

Many different types of cells are used including:

- Single crystal silicon cells
- Polycrystalline cells (less efficient but cheaper to produce than single crystal)
- Gallium-arsenide cells
- Thin film cells of amorphous silicon (easy to manufacture on a large scale, can be flexibly sized and incorporated into building components)

Today's prevalent cell technologies are based on a single junction that can make use of only a portion of the sun's energy spectrum. However, emerging multi-junction cells will allow many layers to use progressive parts of this spectrum. This will result in higher conversion efficiencies.

New types of solar converter polymers cells may be used in future applications. Polymer photovoltaics already have proof of concept and research has been ongoing for the past two decades. Organic polymers have been shown to be very efficient in as electron donors and acceptors. Incremental and generational improvements will continue to

improve cell conversion efficiencies to electricity over time. They could increase to over 50% in the next century.

Space based solar power may become an option for the 2030-2050 time frame as well. In orbit around the earth, cells receive more solar radiation because there are no atmospheric losses and they receive sunlight 24 hours per day. Power could be beamed via microwaves to receiver points on earth were the microwaves could be converted back into electricity. Since the solar cells could be constructed on earth to unfold in space deployment would be relatively simple. Demonstration units for this technology could be operable within 5 years.

The ultimate goals of research are to produce low cost, and highly efficient photovoltaic cells that have long lifetimes. Less intensive cell manufacture, through spray deposition for example, could make solar cells commonplace on buildings and other stationary or mobile energy consumers. One million 4 kW systems on rooftops could give the same power output as one 4 GW nuclear plant.

Solar Thermal

Solar thermal processes concentrate solar energy to heat fluids for end use demands like hot water or to run heat engines to generate electricity or mechanical work. Residential water heating by solar power is already a viable and proven technology. Solar thermal systems could be integrated with PV systems to capture more of the sunlight's spectrum.

Heat resistant plastic components for solar thermal applications could have passive temperature control inherent in the materials. Thermo-chromatic properties would achieve this; for example, the water tanks could turn white and reflect light energy when the water inside reached 100° Celsius. For thermal electrical generation systems, water, molten salts, or liquefied sodium can be used to drive heat engines. Turbines or Stirling engines have been used to convert the thermal energy into mechanical work.

WIND

Wind energy is a plentiful and sometimes powerful resource. Wind turbines extract the kinetic energy from the wind and turn it into rotational energy for electricity production or mechanical work. The power extracted from the wind is proportional to the cube of the wind speed and also proportional to the density of the air mass, a cooler more dense air mass will have more power than a warmer lighter one at the same speed. The power given by a wind turbine can be expressed as:

$$P = \eta \times (0.5 \times \rho \times \pi r^2 \times v^3)$$

Where P is power,

η is the efficiency of converting rotational energy into electrical energy,

ρ is the density of the air,

πr^2 is the area of contact with the blades (circular),

and v is the velocity of the air.

Since the radius and velocity values are squared and cubed respectively, those variables effect the power the most. If the radius is doubled, the power out theoretically increases by a factor of four. The amount of blades sweeping a given area makes little difference to the amount of energy extracted from the wind as it moves through. Wind speed is the most important factor for power output and, in Canada, the average wind velocity can widely vary from different sites. Another factor not mentioned is the capacity factor, this is the ratio of output over the maximum possible (not theoretical) output. The capacity factor of wind power would vary between sites. Off shore wind farms are used in many countries since the wind is usually stronger over water than on land. The towers can be based on the ocean bed or on floating docks.

There are many different types of wind generators. The horizontal axis type is the most common. The vertical axis 'Darrieus' rotors are a more practical design with the generators at the bottom of the unit but are less efficient since the rotors move against the wind for part of the rotation.

Another design idea includes a wind generator that has no moving parts. This design uses the wind speed to push ionized particles against a charged surface. A current is induced to equalize the charge. Work was done on this design in the early 1980's and it was taken to a break even energy balance. Knowledge of ionized particles, electronics, and materials has and will continue to advance. Technologies such as this may be revisited in made viable in the next century.

Taller towers increase the amount of power received from wind turbines because wind speeds are higher farther from the ground. Better tower designs must successfully hold the equipment and spinning rotor in extreme weather conditions. Larger rotors need durable materials that will not fatigue over time. Rotors should be bird friendly as well or placed in non-migratory routes. Wind turbine blades have unique stresses exerted on them and require lightweight and durable composites. Blades made from materials that could shed ice would increase the productivity of wind turbines in the winter months.

As the wind turns the rotor, the rotor axle turns a generator. Currently, a gearbox is required to increase the rotation rate from the rotor. These gearboxes can be large, expensive, and noisy. They also decrease the overall efficiency of the power system. Direct drive designs from the rotor to the generator would involve variable speed devices with power electronics to match the power output to grid specifications.

The intermittent nature of wind power could be mitigated by using it for peaking and intermediate power demand. Although wind is not as reliable as a hydroelectric plant it is not as intermittent as other renewable energy sources. Energy storage devices like flywheels for mechanical energy or SMES systems for electricity could be used to store energy until it was needed. Using wind in a hybrid system with more reliable power sources like diesel can be used to guarantee electricity supply. These types of systems are already in use in select locations.

Other issues surrounding wind power include their appearance and noise. Since windy areas are usually conspicuous, aesthetic issues must be taken into account. Noise issues could be solved through gearbox elimination and better blade design. Land use for wind farms is not as significant as it is for solar energy. Road access is only necessary during construction and the land around the base of horizontal axis wind generators can still be used for other purposes like agriculture.

BIOMASS

The topic of biomass is covered in ETF's ***Biotechnology Focus Group Report*** and the ***Biotechnology Perspectives*** by the McLeod Institute. The focus group mentioned certain points concerning the use of biomass as a renewable energy source.

The use of genetic engineering of plant species to create super species of trees that would grow quickly and be easily harvested and processed was identified as a research goal. The photochemical reactions could be concentrated for large-scale biomass production. Designed microbe or plant species could yield certain valuable or complex chemicals in carbon feedstock processing.

Anaerobic digestors and landfills could be harnessed to produce methane gas. These systems produce methane through the breakdown of biomass without oxygen. The gas can be used to run turbines and generate power. Usually, the amount of biomass in landfills and sewage treatment facilities is enough to maintain an electrical generation system. Using algae and the sun to create combustible gases is also an example of bioconversion of energy from one form to another.

HYDROELECTRIC

One of the major issues surrounding hydroelectric power is the viability of large dams in reducing greenhouse gases. When large areas are flooded, the vegetation that is submerged begins to decay anaerobically (without oxygen) and release methane gas. Depending on the amount of gas released, the electricity generated from could be more GHG emitting than alternative sources. More study on this issue is warranted and for the purposes of this focus group, large scale hydroelectric was considered off the agenda. Notwithstanding large dams, there are still opportunities for small and micro hydro development with minimal impact. Small hydro is generally defined as units producing less than 20 MW of electricity and micro hydro is defined as producing less than 1 MW of electricity.

Hydroelectric power converts the potential energy of water at a high elevation. Water at a certain height has gravitational potential energy and this can be expressed as:

$$E = mgh$$

Where E is energy,
m is mass (kg),
g is the acceleration due to gravity (9.8 m/s^2),
and h is the height or head, in meters.

As the water falls, the plant harnesses the energy and uses it to generate electricity at a certain efficiency, the average electrical power from a dam is expressed as:

$$P = \eta \times 9.8 \times Q \times h$$

Where P is power in kW,
η is the efficiency of conversion,
Q is the flowrate in m^3/s,
and h is the difference in elevation, head.

The conversion efficiency (η) of this process is approximately 60%. Hydropower can also be used for pumped storage of electricity from excess supply or from intermittent sources of electricity like solar or wind power. Low head hydropower include run of river and weir generators that may or may not have reservoirs, these sites have little or no environmental impact but they produce only small amounts of power.

Further advances that in technology that could have effects in the hydroelectric area include inverters, low speed generators, new construction technologies, and biotechnologies.

Better inverters would allow for a better conversion from DC to AC for the grid. Low speed generators could be applied to low head sites to extract the mechanic rotational energy more efficiently by avoiding step-up gearing to increase the rotational speed of the generator. These technological demands are similar to wind turbine needs.

New construction techniques could include in-situ boring and piping. Small boring machines for penstock drilling could be used with plastic penstock piping being soldered on site. Biotechnology applications include the creation of de-icing organisms to decrease ice buildup around dams and the actual creation of biological dams, perhaps from coral reef building organisms.

Potential damage to fish habitat can limit the viability of low head hydroelectric generators. By redesigning turbines to allow fish to pass through without damage, more sites can be exploited. This technology would also be useful in tidal power generators because their turbines must also allow fish to pass.

There are a large number of possible sites for small and micro hydroelectric generators, each site produces a limited amount of energy. The cumulative amount of electricity produced by them are comparable to large fossil fuel or nuclear generating plants. If environmental constraints can be met, 20,000 MW of power could be attained from low head hydroelectric throughout Canada.

THERMAL

Thermal energy gradients from the earth or water can be used in heating and cooling buildings. Heat is a low-grade energy as compared to other energies like electricity. For example, the movement of heat energy through pumping for space conditioning needs is

thermodynamically more efficient than the conversion of electricity directly to heat. This gives this type of heating and cooling system an inherent advantage.

Heat can be transferred from one area to another using a fluid in a heat pump. The refrigerator exemplifies this concept. Heat is dissipated or captured from a sink that is sufficiently large enough not to be effected by the transfer. In geothermal systems the sink is the earth, in hydrothermal systems it is a large body of water. Ambient air can be used for this process as well, but it is not always economical in Canada.

Heat pump systems can be open or closed looped. Open looped systems use ground or lake water and discard it after heat is extracted or added. Closed loop systems use a refrigerant fluid that is constantly recirculated into the earth or a lake. These types of systems move many times more thermal energy for heating and air conditioning than if the electricity was used to heat the home directly.

TIDAL, WAVE, AND CURRENT

Large amounts of energy are stored in tidal flows. In tidal energy systems, water flows through a turbine to enter an enclosed area and flow out through a turbine as the tide goes out. Electricity is created with a two-way turbine. An alternate design involves two enclosed areas, the tidal waters are captured in on and slowly released into another through a turbine. The water from the second enclosure is released at low tide. When timed correctly, this can produce a constant flow of electricity.

However, tidal power stations have a high capital cost and environmental problems. Fish kills are common in turbines and the water storage process upsets marine ecosystems. Alternative turbine designs could be used for this technology. An optimum location for this technology is at the Bay of Fundy where a tidal power station already exists.

Wave power in the ocean can create tremendous amounts of energy. When the wind pushes the ocean surface, it transfers massive amounts of potential energy to the water. The best way to capture some of this energy is with oscillating water column (OWC) technology. When waves hit an OWC, the air inside is compressed and forced through air turbines via a one way valve. When the air returns, it also passes through a one way valve again, and turns the turbine. Wave power devices are usually designed to float in the ocean and can be damaged by powerful waves and storms.

Ocean current power is similar to run of river power generation. Part of the current's kinetic energy is used to spin a turbine. This is also a low impact technology.

HYBRID SYSTEMS

In the absence of sufficient storage or generation capabilities, hybrid systems can be used to provide for end-use demands. These involve using the energy from different sources to create a dependable generation source. This usually involves combining renewables with other renewable energies or fossil fuels.

Active solar units could be combined with many units to take advantage of solar power. Hybrid solar PV and thermal systems could be used for heat and electricity. Active solar and wind systems could deliver a more constant supply of electricity. Combining these with fossil fuels to deliver energy when the renewable sources are not producing will yield an autonomous energy system for off grid communities.

Individual buildings may become autonomous from the grid through renewable-fossil hybrid systems (see ETF's ***Buildings Focus Group Report***). Active solar shingles and solar thermal and wind energy systems could be used with or without local generation on site. This could make buildings contributors as well as users on a grid.

ENERGY STORAGE & TRANSPORT

Renewable energies could become more suitable for different applications depending on their energy storage and transport capability. Hydroelectric systems are not only generators of energy but also act as energy storage devices through pumped storage. Pumped water storage is a commonly used energy storage practice that involves pumping water up into a basin when there is surplus power and releasing it over when extra power is needed. Energy storage could be done for peak shaving or on a seasonal basis.

The most common energy carrier used today is electricity, but hydrogen and other liquid fuels can also transport energy. All of these technologies require a certain infrastructure set of technologies to make them viable.

ELECTRICAL STORAGE

There are technologies available now or that can be further developed that could influence energy storage n the next century. These include batteries, flywheels, reversible fuel cells and SMES systems.

Current technology batteries may be further developed to have significant storage and longevity capabilities. Lead-acid batteries are low performance compared to other dry battery technologies. Nickel-Cadmium or Lithium batteries may become increasing more useful for storing relatively small amounts of power. Lithium-polymer batteries that are light and have a long life and low cost may be available in 10 years.

Flywheels may be developed to store large amounts of mechanical energy. To store large amounts of energy a flywheel must have a fast turning speed and a large moment of inertia. The moment of inertia is dependent on the mass, geometry, and radius of the spinning object. The kinetic energy stored in a flywheel is expressed as:

$$E = 2 \times \pi^2 \times f^2 \times p \times m \times r^2$$

Where E is the rotational energy,
f is the frequency (cycles/second),
p is variable dependent on the geometry of the flywheel,
m is the mass in kg,

r is the radius of the object.

The frequency and radius are important values in this equation. The challenge to material scientists is to develop lightweight materials that will not break apart at high rotational speeds. Lightweight, high tensile strength materials are preferred because a higher radius has more influence than a higher mass and too large of a mass could cause a flywheel to break part in motion. The use of magnetic bearings and the placement of the flywheel in a vacuum house helps to reduce frictional losses from the unit. However, flywheels do tend to dissipate their energy overtime so they are not optimal for long term storage.

SMES (Superconducting Magnetic Energy Storage) systems can be used as high-efficiency, high-capacity energy storage systems to compensate for large daily swings in power requirement and to stabilize transmission systems against disturbances. SMES technology could also make some types of renewable energies more feasible due to its storage ability. In a SMES system, energy is stored by circulating a DC current through a superconducting coil. Normally electricity would be lost to heat due to the resistance of the wires but since a superconducting wire has no resistance to DC power, the energy can be stored indefinitely. SMES systems can rapidly accept and deploy charge, limited by the conversion for AC to DC or vice versa. Also since there is no conversion of the electricity to another energy form, the theoretical efficiency can be very high.

Currently these devices are available but run at a very low temperature to induce the superconductivity effects. Further work in superconducting materials could provide large amounts of 'high temperature' superconductors that operate at liquid nitrogen temperature, 77 K or -196°C. Continued advancements in superconductors could provide their properties at room temperature or higher, this would make a superconducting infrastructure easier to implement since no cooling would be needed.

Another energy storage technology is the reversible fuel cell. This involves running the fuel cell reaction in reverse to create the fuel cell fuel with electrical input. This type of technology may be on line in 15-20 years time. For more information on hydrogen and fuel cells, see the ***Hydrogen Perspectives*** by Hydro-Québec and ETF's ***Hydrogen Workshop Report***.

THERMAL STORAGE

Thermal storage is used in passive solar systems and in heat transfer fluids for heat pumps. High quality thermal storage requires materials with high specific heat and certain heat capture and release abilities. Currently we use water due to its ability to hold large amounts of thermal energy. Although the latent heats of water are high, it changes between phases at the wrong temperature for building uses. Phase change crystal and waxes have been developed that store and release heat without changing temperature. Glauber's salt (sodium sulphate deca-hydrate) melts at 30°C and has a high latent heat of fusion, about 2/3 that of water. Developing phase change materials for 22°C would be optimal for building applications.

Closed loop heat pumps and other technologies need fluids to transport heat from one location to another. These fluids need to exhibit certain qualities to be effective. They need to have a high heat capacity so they can transfer large amounts of heat with a limited flowrate. Because of the wide variety of temperatures sometimes involved, they need to be thermally stable and non-freezing so their properties are consistent. Since these fluids are usually being constantly recycled, they need to have a low viscosity, this reduces the friction in the flow. Finally, they should also be non-corrosive and so they do not damage the piping and limit the lifetime of the unit.

ENERGY TRANSPORT

Energy can be transported by electricity, microwaves, or as chemically stored energy in hydrocarbons or hydrogen. In general, the less we need to transport energy, the less is lost travel and conversion.

The use of microwave power transfer makes technologies like space based solar more feasible. Microwave transmitted power can be used for earth/space/earth transmission as well as transmission over rivers and areas where power lines are not feasible. This technology is being used on a trial basis.

Electricity is the most common energy carrier and one of the best for renewable energy sources that transform rotational energy to electricity, like wind and hydropower. The conversion of rotational energy to AC power is about 90% efficient. High voltage transfer of electricity allows for little loss in transmission. However, possible arcing with the earth limits voltage increases. Higher towers or better insulation around wires may make higher voltage transmission possible. Superconductors and high voltage transmission could also ensure the continued use of this technology.

As power electronics develop, renewable energies could be better conditioned to add to the electricity grid. There are implications for renewable technologies in the way in which the electrical grid is set up. For example, the capacity of the grid for storage increases with the size of the grid.

A RENEWABLE ENERGY EMPHASIS

In visioning possible futures for renewable energy three methods were used.

- A chronological step out to the year 2050 identifying technological milestones and energy technology mixes
- A visioning set in the 2030 to 2050 era outlining how we could live, work, and travel
- A geographical perspective developing likelihood of technologies being used in certain areas of Canada

Members of the focus group gave their input in all areas.

STEP-OUT INTO THE FUTURE

This vision involved looking at the state of the energy system and renewables today and projecting it into the future. This vision felt that the energy system needed to deal with efficiency first. The amount of efficiency in the economy could increase as much as a factor of four. This also involves using the appropriate type of energy for an end use demand. For example, a high-order energy like electricity would not be used for heating.

Eventual fuel switching from to less carbon intensive fuels like natural gas could also take place. At the same time the use of renewables would also grow. Presently the energy mix in Canada uses about 17% renewable energy (including hydro). This could double to about 30% by the 2050 time frame.

By 2020, most building heating, cooling, and hot water needs could be provided for with ground source heat pumps and solar systems. By 2030, there could be one million PV rooftops in Canada giving 4000 MW of solar power at a capacity factor of 16%. Up to 20% of residential buildings could be self sustaining by 2040.

Wind power could continue to drop in price until it becomes price competitive with fossil fuels by deploying units with new technologies and improved efficiencies. It could reach 10,000 MW by 2030 and 20,000 by 2050, with a capacity factor of 30%.

Biomass could continue to see its share rise in the market by increasingly using forest and pulp wastes. Small and micro-hydro development will continue to grow using almost all the available capacity by 2030, hydro could account for 90,000 MW at that time with large hydro providing 70% of that amount. Run of river and low head hydro systems could amount to 20,000 MW by 2050. By 2040, there could be 2,000 MW of ocean current, wave, and tidal systems installed around Canada's coast.

A POSSIBLE ENDPOINT

This visioning involved determining the possible ways we could live in 2030-2050. This exercise did not step out from today's world towards the next century. Instead, it was an effort of placing oneself in that time frame and looking at Canada's energy system. The results from this exercise were that technologies like nuclear, hydroelectric, wind, and PV would be important in an increasingly electrified economy.

The information age technologies could give us better control and autonomous systems and efficient local manufacturing.

With the advent of automated PV manufacturing, solar farms may become unnecessary. Solar cells could be placed as shingles on buildings and along roadways. PV paint could be developed for outdoor use. Wind power could also be used in a similar way by placing portable units in appropriate spots. Utilities and local users could match their energy generating system to demand needs through the use of advanced energy storage technologies. Large scale energy storage systems for thermal and electrical systems could be in place.

Regional mobility could be achieved through the use of personal vehicles and light rail electric trains. Communal vehicles could be used in local travel and run on hybrid or electric engines. Liquid fuels could be made up as part or entirely biofuels. Cargo movement throughout cities could be done differently without using roads or trucks. Increased electronic communication transactions could make a lot of local travel unnecessary.

THE GEOGRAPHIC PERSPECTIVE

The third and final visioning exercise was to look at the use of renewables from a geographical perspective. If there is to be an increasing use of renewable energy in Canada, there would be some fundamental changes to the way the energy system is maintained. There could be an increase in the amount of off grid communities, or power generation could become more decentralized. There will be overlap and competition between renewable technologies.

Geographically, technologies like wind and hydro are site specific while solar and ground source heat pumps are more uniformly distributed. Population distribution throughout the country has implications for energy transportation and source. Urban areas can make use of landfill gas and waste biomass as well as local agricultural wastes. Large urban centers could be the first to install superconducting technologies in their infrastructures. Rural communities and industries can especially make use of forest or prairie biomass and locally generated power. Hydrothermal based heating and cooling systems may be used in communities around large lakes.

Southern areas of Canada could use more active and thermal solar designs as well as ground source heat pumps. Northern areas may use more on wind and active solar. Large microwave receiving dishes could pickup space based solar power beamed to remote northern communities. Coastal areas would use tidal and wave power and more wind power since those areas tend to be windier.

Wheeling power between the eastern and western coasts could use energy more efficiently. For example, BC's peak power could be supplied by using Québec's off peak power. Trans-continental wheeling could be done as well since Canada's peak demand is in winter and the US's peak demand is in the summer. Power sharing could be done

between Québec and BC dams as pumped storage. Storage can also be done in areas of the country with compressed air in depleted oil and natural gas reservoirs.

Further work resulting from these discussions includes resource assessment on a fine scale for prospects on the best wind solar locations. Remote sensing can provide a hydrological assessment for potential hydroelectric systems to build a renewable energy map. Viability areas for different technologies would assist in long term decision making.

FUNDAMENTAL REQUIREMENTS

TECHNOLOGIES

ETF can extrapolate upcoming technologies from what concepts we have gathered and by looking for commonalties and complimentary technologies through technological integration. Significant and breakthroughs will occur in the future that we cannot foresee, however, given the length of the timeline at hand, there will be opportunities to revisit and make changes in light of new innovations.

Energy storage devices for heat and electricity have been brought up frequently in this focus group as well as others. Better power electronics and better process were also mentioned. Materials that have better properties or that are smart or intelligent are also a cross cutting need.

ELECTRONICS

Electronics play an essential part in power processing and conditioning. Inexpensive, efficient, and reliable solid state control systems are needed. Better converters, inverters, conditioners and other power electronics could increase the overall efficiency renewable systems. Better control algorithms and hardware can enhance these electronics. As these technologies become more prevalent, better protection systems for automated production or satellite communications could be needed.

MANUFACTURING & CONSTRUCTION

Through the use of computerized structural design and dynamics methods, renewable systems will become more complicated and error sensitive. Production of objects like wind or hydro turbines could be done in small-scale steel or brass works to produce highly engineered products. Automation and improvements to quantity production techniques could effect the PV industry. This could allow for mass production of efficient and cheap PV cells for all types of uses.

New construction materials could include substitutes for concrete that could be used on projects that require small quantities. On-site manufacturing of high grade plastics and other components would assist in rural construction of small or large renewable power stations.

MATERIALS

As previously mentioned, there are advances needed in converter polymers for PV, heat transfer fluids, and phase change materials. In general, the requirements of these and other materials are; low cost production, lightweight, durability, temperature resistance, and ease of manufacture.

These also apply to new plastics along with passive controls. Passive controls built into plastics should be automatic and tunable. This includes electro- or thermo-chromatic materials that change their colour depending on electric or thermal inputs. These types of materials could be used in many thermal applications. These could also be adapted to switchable glazing on windows that allow them to change their transparency and other properties like absorptance and transmittance. Electro-chromatic materials may take up to 10 years to be developed and thermo-chromatic materials may take 20 years to develop.

Advances in material science may make thermo-electric systems viable as a long-term technology. Thermo-electric systems can heat up or cool down depending on the direction which the current flows between the two metals. Using a voltage difference to create temperature differences is called the Peltier effect. Also, by applying heat to one of the metals a current can be generated. Using a temperature difference to create a voltage difference is called the Seebeck effect. These systems create no noise and have no moving parts. Currently, these types of systems are used only in niche applications since it is usually more efficient to heat and cool or to generate electricity in other ways. Developing materials in which the current conducts but the heat doesn't would increase the power of these types of systems.

Materials with very fine surfaces could be further developed for bearing friction and lifetimes. Nanotechnology may be involved in the development of homogeneous, low friction surfaces. Ionic and electronically productive polymers for PV use may become available replacing the need for doped metal semiconductors. It may take 20 to 30 years for semiconductive and conductive polymers to be commercialized.

For more information on advanced materials and manufacturing techniques in the next century, see ETF's **Materials and Manufacturing Focus Group Report.**

The technological possibilities for renewable technologies can be summarized in bullet form as follows:

Active Solar

- Multi-junction photovoltaic cells that use a very wide range of the electromagnetic spectrum.
- Solar tracking by non-mechanical means.
- Optical films that concentrate solar energy.
- Polymeric based solar cells as opposed to solid state semiconductors.

Passive Solar

- Phase change materials that change state at 22° C.
- Wallboards and floors that change their crystalline structure for heat storage.
- Low cost, switchable window glazing.

Thermal Systems

- Thermochromatic materials for water heating that change their optical properties with temperature, i.e. heater changes colour from black to white at 100° C.
- Advanced heat transfer fluids; Non-corrosive, non-freezing, high heat capacity, low viscosity.
- Heat resistant plastic components.

Wind Power

- Micro-friction bearings for moving parts.
- Low RPM generators to eliminate gearbox assemblies in turbines.
- No moving part power generation.
- Wind blade materials that can shed ice.

Hydroelectric

- Creating small hydro structures through biological means.
- In-situ drilling and piping by remote machines for easier and more versatile construction.
- Low speed generators for low head sites.

Biomass

- Hydrogen generation through anaerobic digestion of biomass.
- Use of bark in other hard to process biomass in fuel production.
- Genetically engineered biomass that produces more ethanol.

FUTURE CHALLENGES

Throughout the world there is an increase in the use of renewable energy. In Canada, there are some services and niches that are best served by renewable energy. In other applications, renewable energy sources could be in competition with each other and fossil fuels. Carbon dioxide sequestration with hydrocarbon plants may make these finite energy sources more attractive but they will still eventually be depleted. If costs can continue to be lowered and fossil fuel processing pushes the cost of hydrocarbon based fuels higher, there may be a large market for renewable energy. Though this group did not see an energy economy based entirely on renewables, they felt that as the technology developed it would be able to compete in the energy market and take a large share.

As the potential impacts of climate change increase, there will be increasing pressure on science to clarify and assist in recommendations. Without a consensus, society has little impetuous to move away from the status quo. If action is delayed in response to climate change, an unpredictable climatic system could adversely effect the bulk of the human population.

CONCLUSIONS

This focus group was the last in a series of meetings and many of the points covered in this focus group came up in previous focus groups. The potential roles outlined for these technologies do not depend on feasibility alone, but also on other social, economic, and environmental factors. However, without the technical knowledge, these solutions will not be feasible if needed.

If the issue of climate change continues to be held as important, technologies will have to be judged not only by cost but also by their environmental costs and benefits. Renewable energies have an inherent advantage in this area. The parallel development of other technologies in fossil fuel production or electrical transmission and storage may make renewable energy sources more or less viable for the beginning of the next century. The revival of nuclear power and other such issues are unknowns as we look into the future.

GLOSSARY

Absorptance
The ratio of the radiation absorbed by a surface to the total energy falling on that surface described as a percentage.

Active Solar Energy
Solar radiation used by special equipment to provide space heating, hot water or electricity.

Anaerobe
An organism that grows in the absence of oxygen.

Average Hydro
Rain, snow and runoff conditions that provide water for hydroelectric generation equal to the most commonly occurring levels. Average hydro usually is a mean indicating the levels experienced most often in a 104-year period.

Alternating Current (AC)
Electricity that fluctuates between directions. Electricity usually fluctuates at 60 cycles per second (Hz) with a root mean square average of 120V.

Base Load
The lowest level of power production needs during a season or year.

Battery
A device that stores energy and produces electric current by chemical reactions.

Band Gap
The amount of energy required allowing a current to pass. This gap is defined as the energy difference between the valence band (lower energy) and the conduction band (higher energy). The valence band is filled with electrons, whereas the conduction band is empty. When the electrons obtain energy from an applied voltage, they can jump to the conduction band. Conductors effectively have a band gap of zero while semiconductors have a band gap of up to 5 electron volts.

Bioconversion
Processes that use plants or microorganisms to change one form of energy into another. For example, an experimental process uses algae to convert solar energy into gas that could be used for fuel.

Biomass
Energy resources derived from organic matter. These include wood, agricultural waste and other living-cell material that can be burned or converted to produce energy or fuels. This also includes algae, sewage and other organic substances that may be used to make energy through chemical processes.

Biosphere
The zone at and near the earth's surface where all life exists. Also refers to all the living organisms on earth.

Biotechnology
A collection of technologies that use manipulation of living cells and/or biological molecules, especially at the genetic level, to solve problems and make useful products.

Capacity Factor
A percentage of how much of a power plant's capacity is used over time. For example, typical plant capacity factors range as high as 60% for fossil fuels and 70% for cogeneration.

Demand Side Management
Planning, implementation, and evaluation of utility-sponsored programs to influence the amount or timing of customers' energy use.

Direct Current
Electricity that flows continuously in the same direction.

ETF
Energy Technology Futures

Extra High Voltage (EHV)
Voltage levels higher than those normally used on transmission lines. Generally EHV is considered to be 345,000 volts or higher.

GHG
Green House Gas

Genetic Engineering
The manipulation of an organism's genetic endowment by introducing or eliminating specific genes through modern molecular biology techniques. A broad definition of genetic engineering also includes selective breeding and other means of artificial selection.

Heat Capacity
The amount of heat necessary to raise the temperature of a given mass one degree. Heat capacity may be calculated by multiplying the mass by the specific heat.

Ionized Particles
Particles with an electrical charge.

Joule (J)
The SI unit of energy: $1\ J = 1\ kg*m^{2}*s^{-2}$.

Microwaves
Electromagnetic radiation with wavelengths in the range of 10^{-i}. It is between infrared and radio wavelengths on the electromagnetic spectrum. The wave beam can deliver electrical energy over long distances.

Municipal Solid Waste (MSW)
Locally collected garbage, which can be processed to produce energy.

PV
Photovoltaic

Peak Load
The electric load that corresponds to a maximum level of electric demand in a specified time period.

R&D
Research and Development

Renewable Energy
Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and biomass. These also include some less-developed sources such as tidal power, wave power, and currents.

Renewable Resources
Renewable energy resources are naturally occurring, but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable resource applications include bulk electricity generation, on-site electricity generation, distributed electricity generation, non-grid-connected generation, and demand-reduction technologies.

S&T
Science and Technology

SI
Système International d'Unités (International system of units)

SMES
Superconducting Magnetic Energy Storage

Semiconductor
A material with a band gap that has to be overcome before a current can flow. The value of the band gap determines whether a substance is a semiconductor or an insulator. The fact that a semiconductor acts as a conductor in the presence of an electrical field is what makes it so valuable to the computer and technology industries.

Stirling Engines
An external combustion engine that converts heat into useable mechanical energy by the heating (expanding) and cooling (contracting) of a gas such as helium or hydrogen.

Watt
The SI measurement of power in joules per second. Watts can be expressed in kilowatts (kW, 1000 watts), megawatts (MW, 1,000,000 watts) or gigawatts (GW, 1,000,000,000 watts).

Wheeling
Using a utility's lines to transport power from one neighboring system to another.

Transmittance
The amount of light absorbed by a semi-transparent solid.